Where are the stellar coronal mass ejections?

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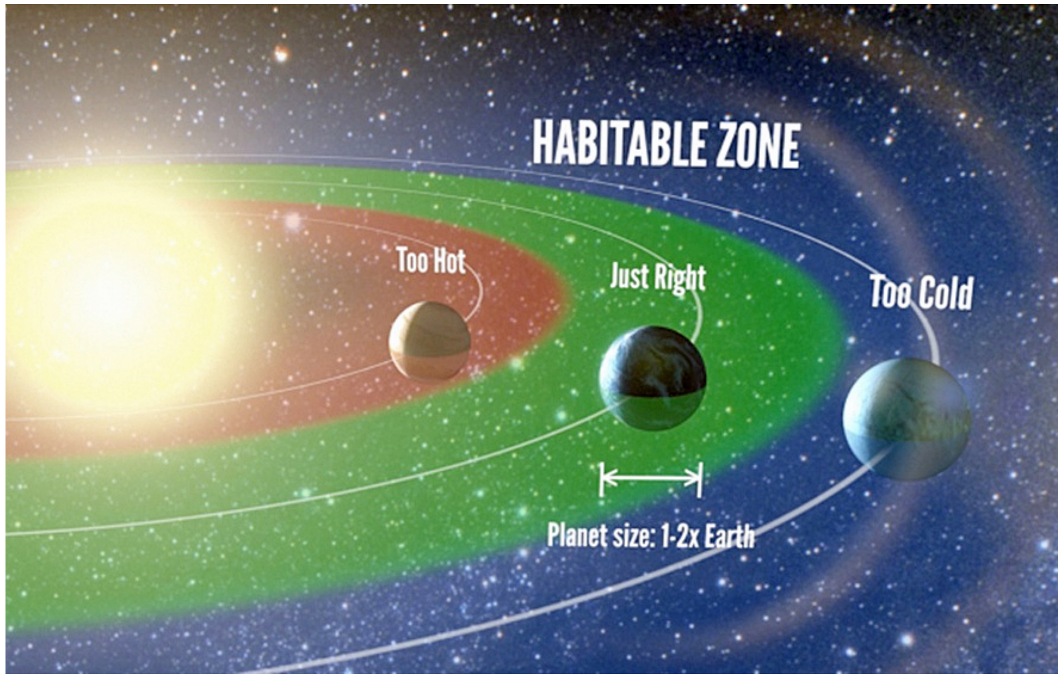
Why do we care?

The most common definition of a circumstellar habitable zone is based on the incoming stellar flux (distance):

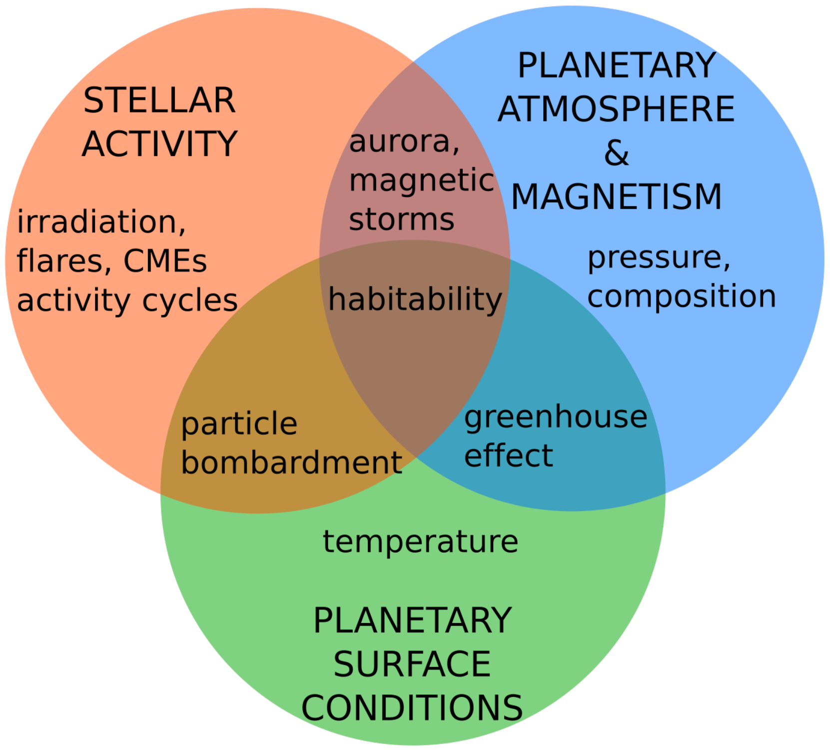
In astronomy and astrobiology, the ***habitable zone*** *is the range of orbits around a star within which a planetary surface can support liquid water given sufficient atmospheric pressure.*

(Wikipedia)



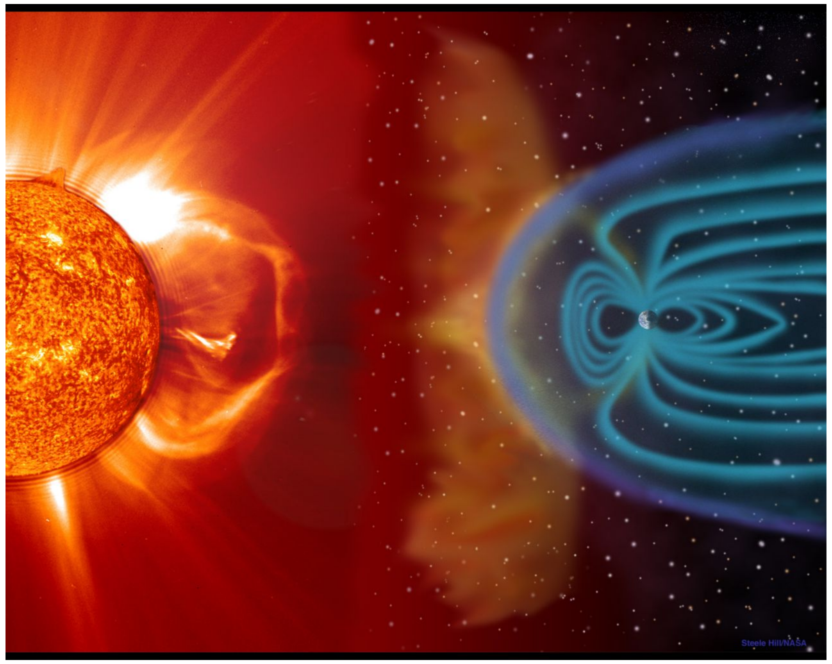
Why do we care?

Factors of habitability are much more complex than just the incoming flux, stellar activity might cause problems



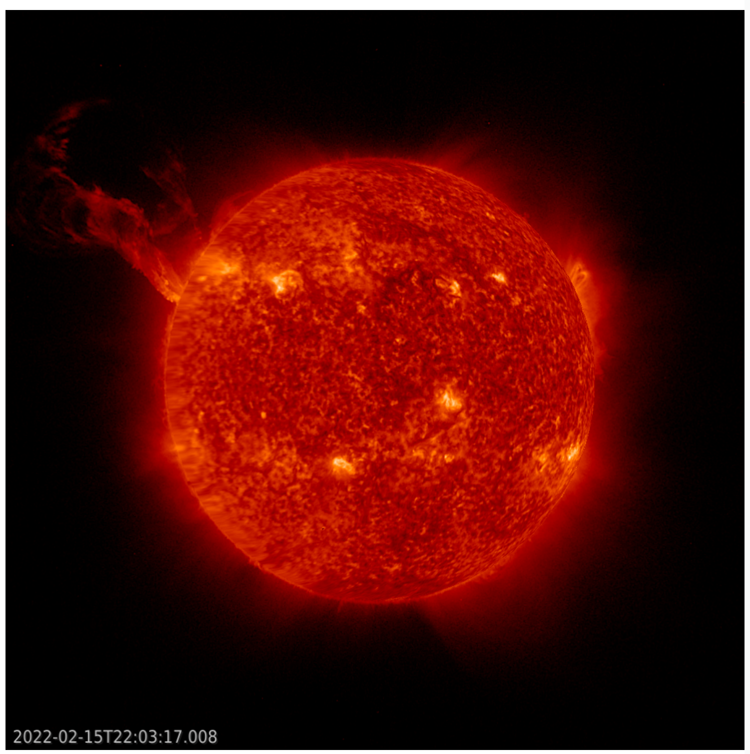
A large number of energetic transients can erode/destroy planetary atmospheres over time:

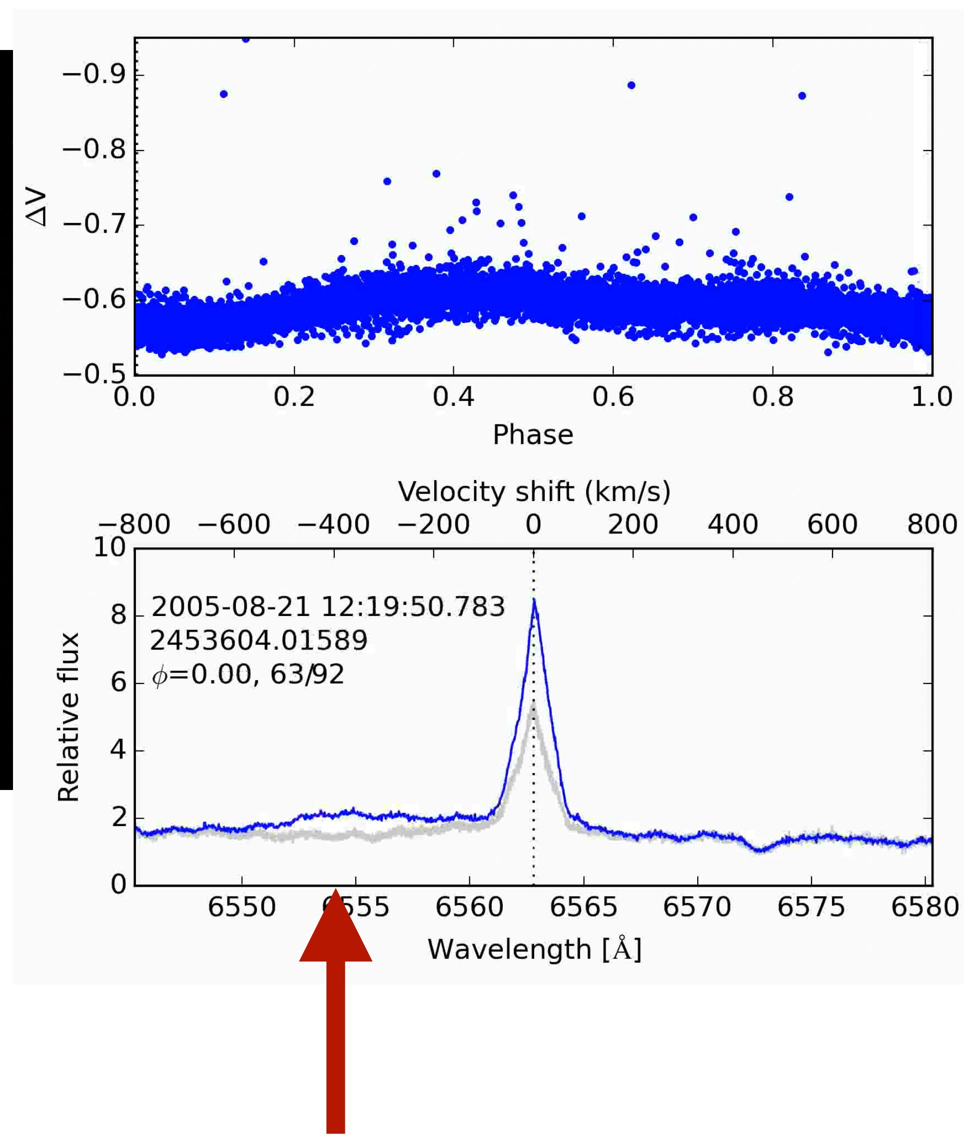
- X-ray/EUV heating
- CME induced ion-pickup



Flares are relatively easy to detect due to their typical light curves; for CME detection the Doppler-signature of the ejecta can be used as tracer

- X-ray detection (Argiroffi+, 2019NatAs…3..742A)
- no luck in radio regime yet (Villadsen 2017PhD thesis)
- most detections in optical/Balmer lines





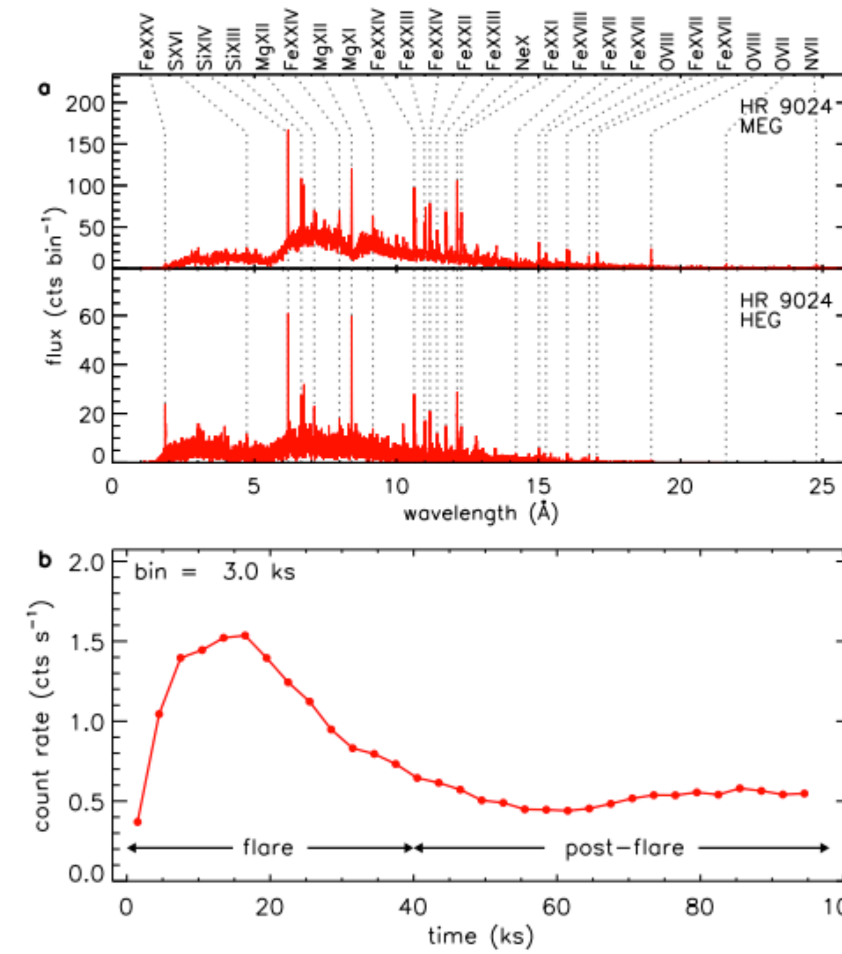
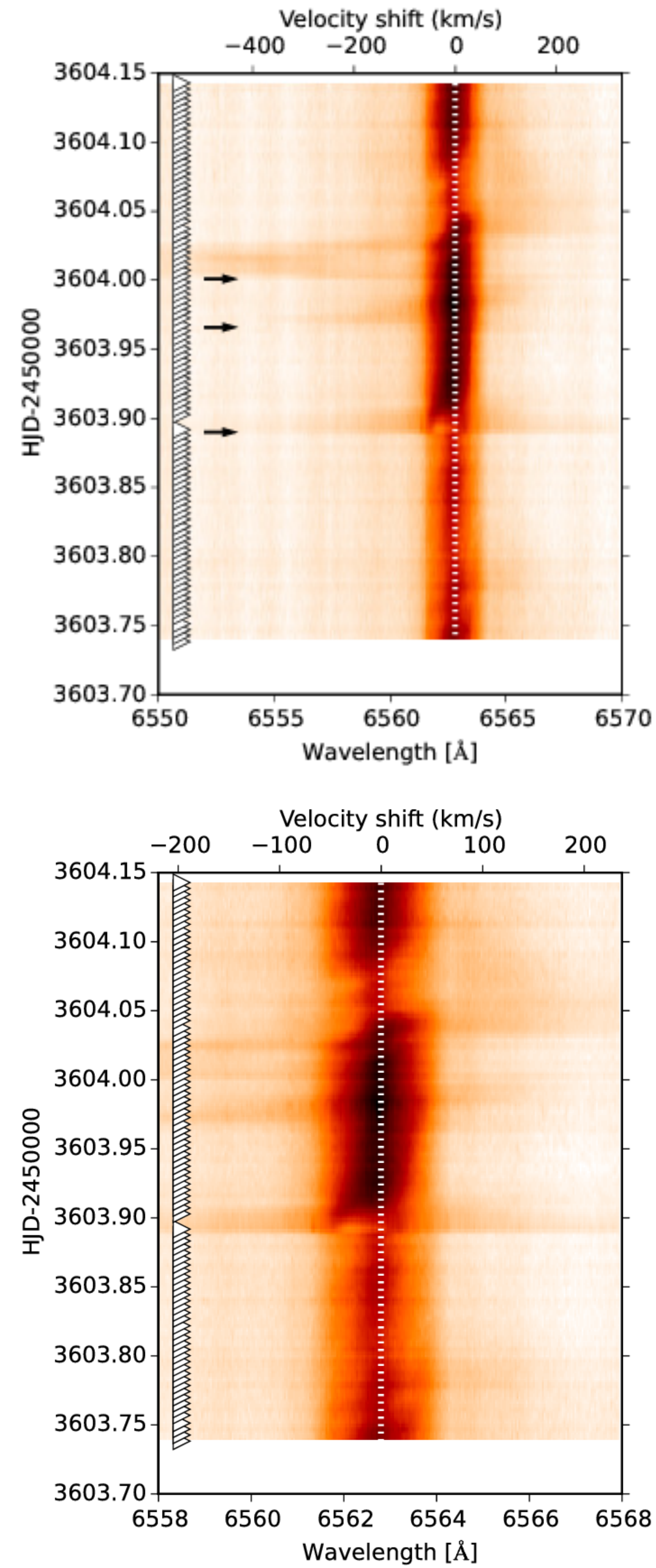


Figure 1: Observed X-ray spectra and light curve of HR 9024. **a**, X-ray spectra collected with the Medium Energy Grating (MEG) and High Energy Grating (HEG) during the 98 ks long *Chandra* observation, with the strongest emission lines labeled. MEG and HEG bin size are 5 and 2.5 mÅ. **b**, X-ray light curve of registered during the *Chandra* observation, obtained from the ±1 order spectra of HEG and MEG.

Argiroffi+, 2019NatAs…3..742A

A lucky series of transients on V374 Peg

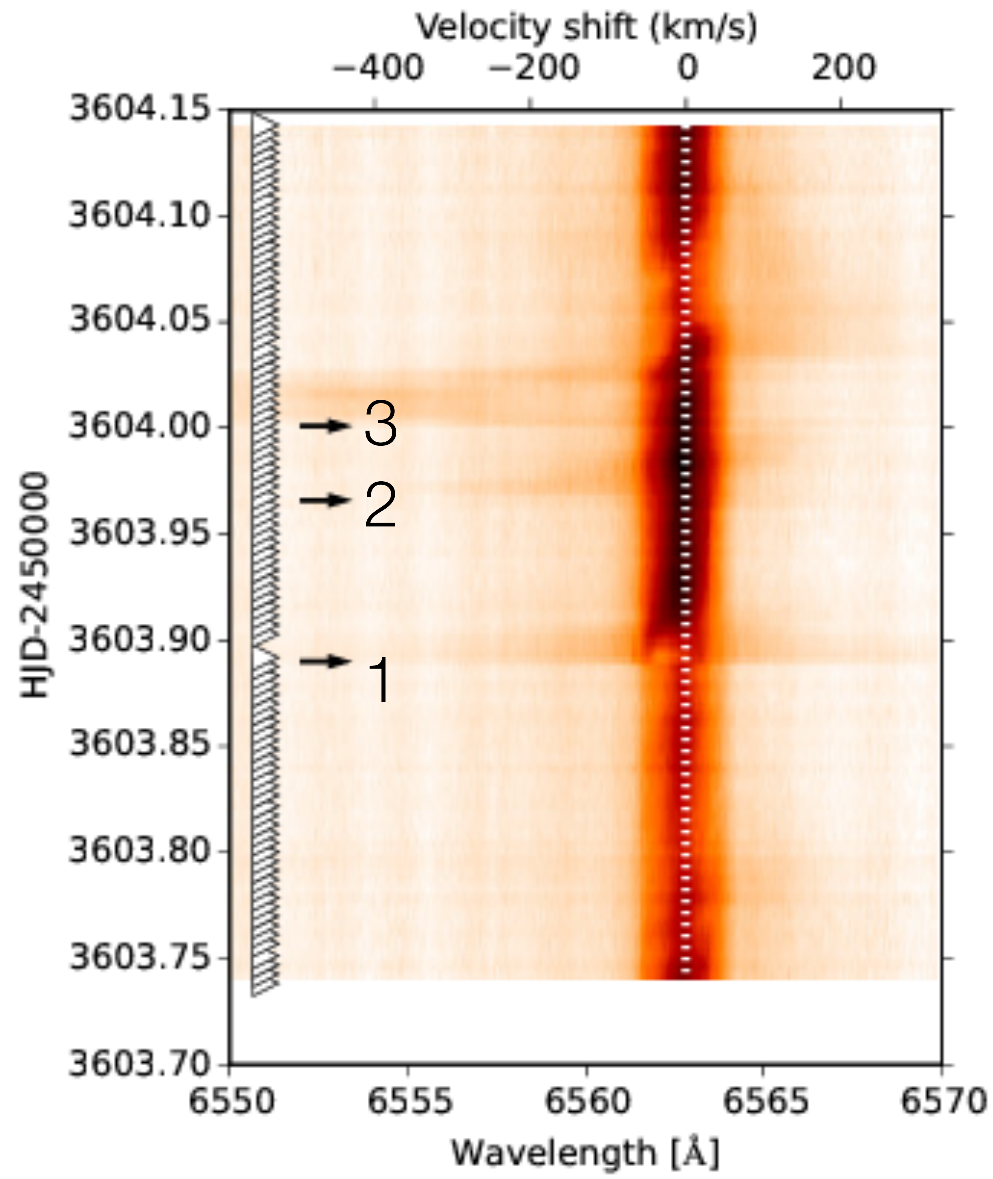
- Until recently most of stellar CMEs were found serendipitously
- Same is true for this event: we found it accidentally when looking for supplementary spectra for our observations in the archives



Vida et al. 2016 A&A, 590, 11

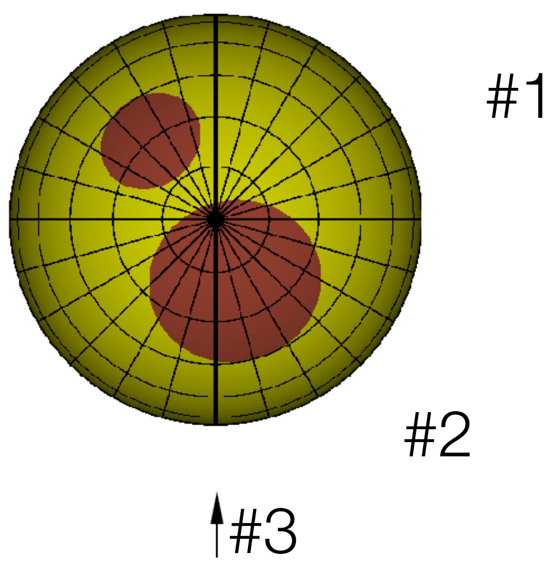
Flares and multiple coronal mass ejections in the Hα region

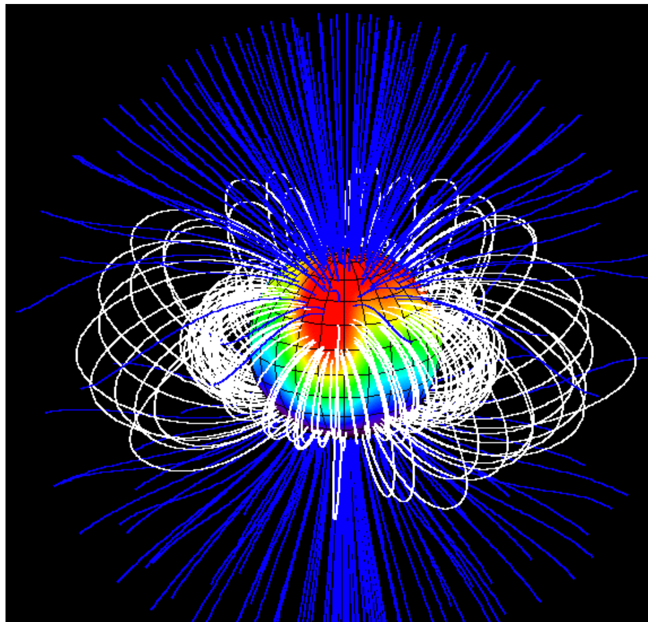
- M4 dwarf: escape velocity ~580km/s
- events 1&2: projected v~350km/s
- #3: v~675km/s → above v_e
- only event that can be compared directly to photometric spot models and magnetic field structure!



Detailed modelling in Leitzinger+

(2022 MNRAS 513 6058)



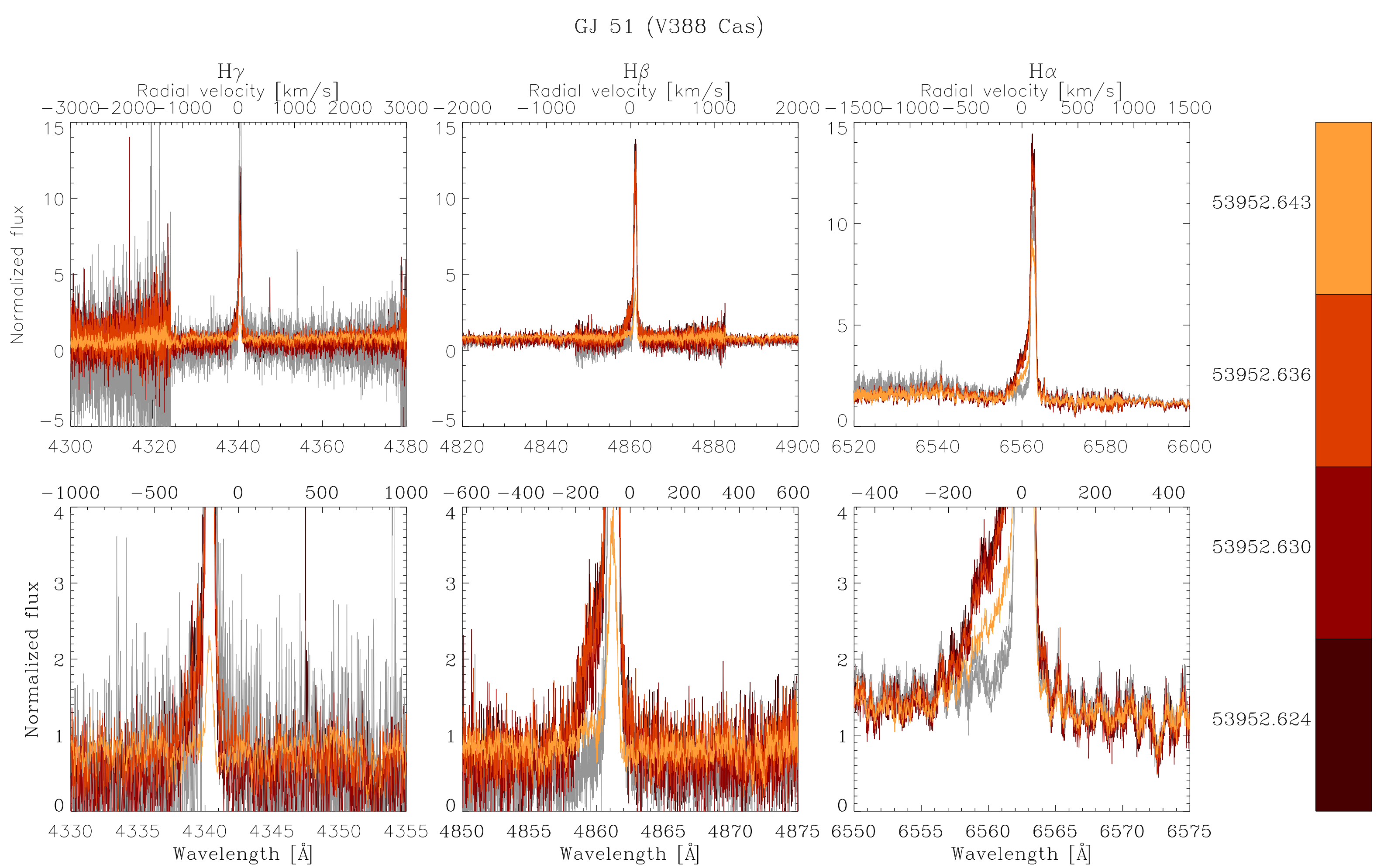


Vida et al. 2016 A&A, 590, 11

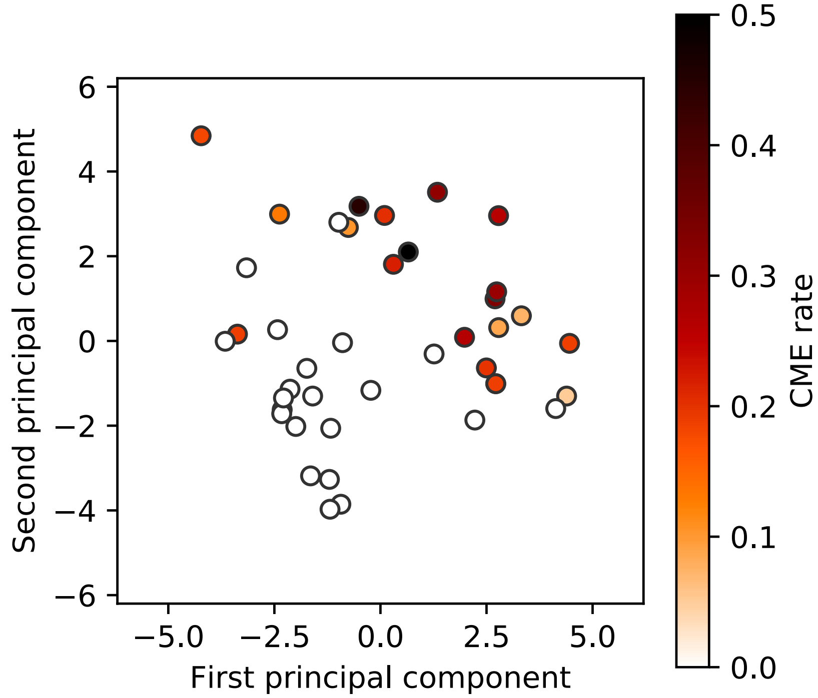
Donati+ 2006 Sci, 311, 633

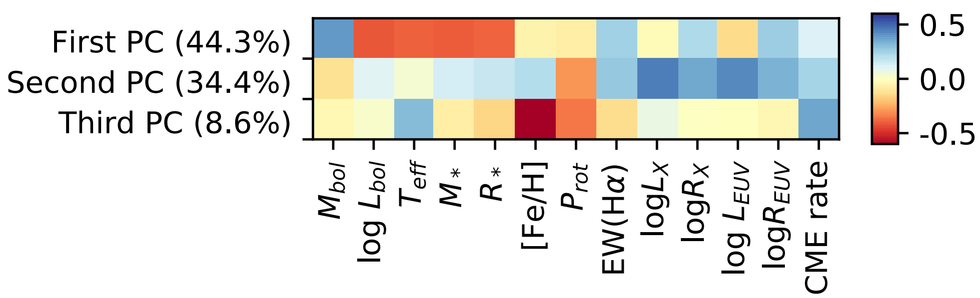
Is there more? Archive data of M-dwarfs

- We checked ~400 late-type stars (M-dwarfs within 15pc and some additional objects) in the Virtual Observatory archives
- More than 5500 spectra - 1200 hours of observation downloaded (mainly from CFHT & Bernard Lyot Telescope)
- We checked the Hα, Hβ and Hγ regions visually for spectral asymmetries
- ~500 such spectra on 25 objects, 9 larger events (still the one on V374 Peg, that gave the idea, being the best)
- Most events connected to enhanced Balmer-peaks (flares), as on the Sun
- For the first time we have enough data for statistics!



Vida et al. 2019A&A...623A..49V



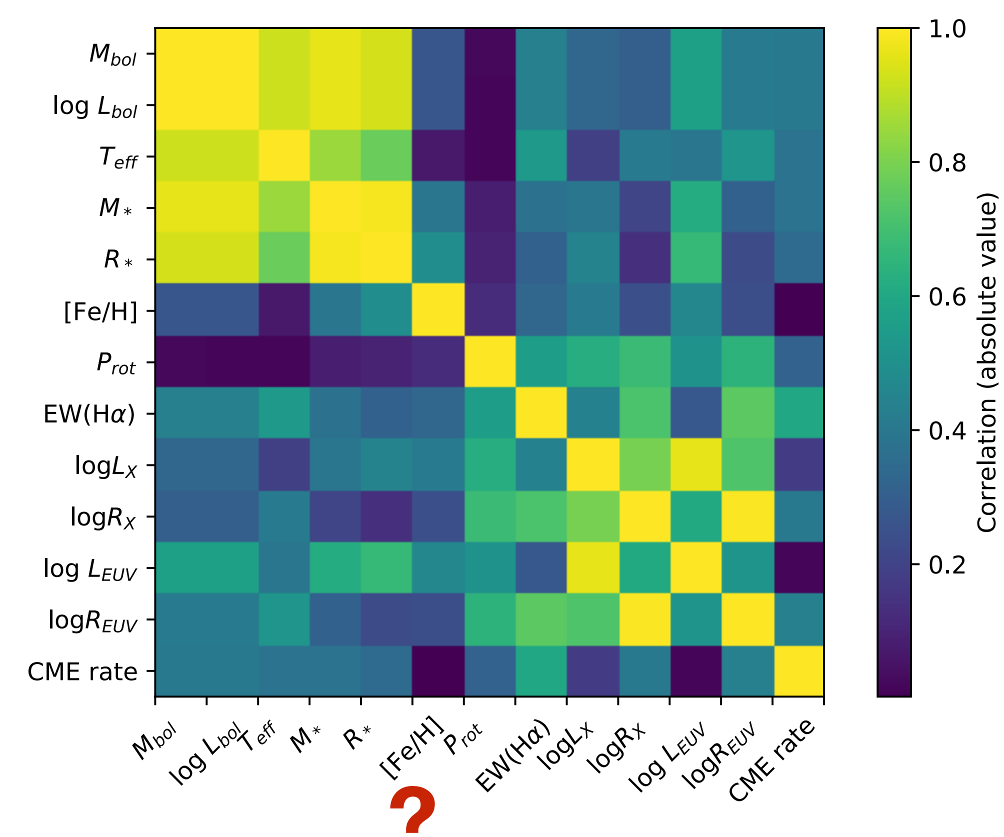


- From principal component analysis (PCA) it seems that line asymmetries are more frequent on later-type more active objects – these are known to have more flares (on the Sun flares almost always are accompanied by CMEs)
- While this seems intuitively obvious, stronger magnetic fields could be blocking CMEs in the stellar coronae

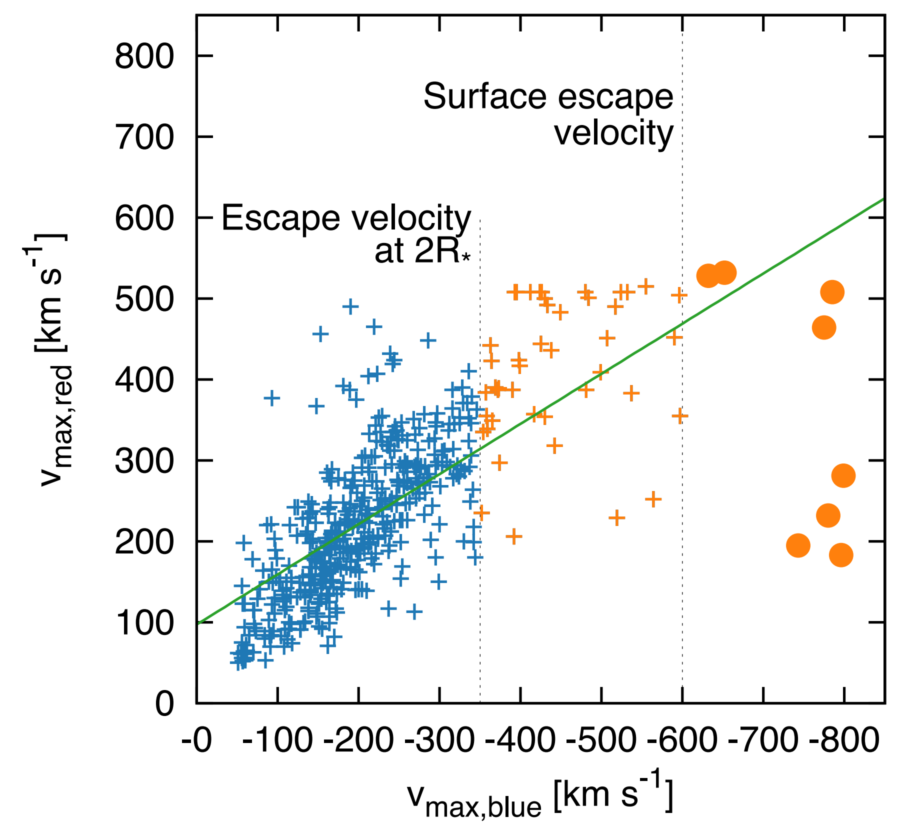
the obvious — smaller stars are cooler, etc.

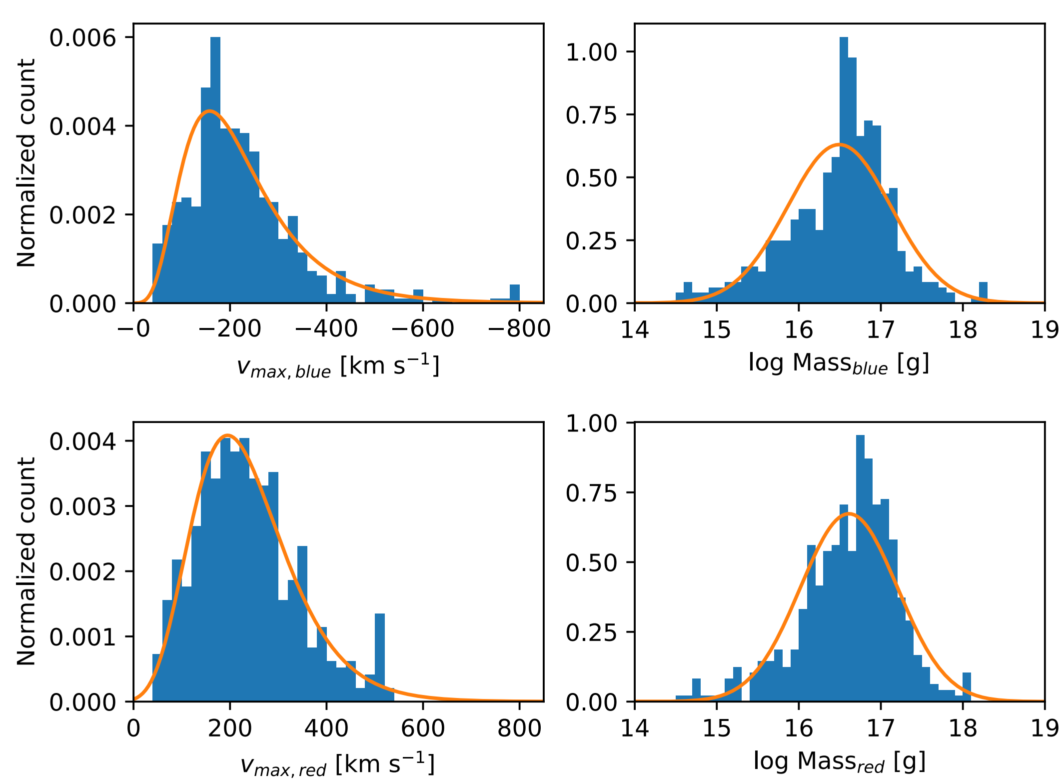
fast-rotating stars are more active

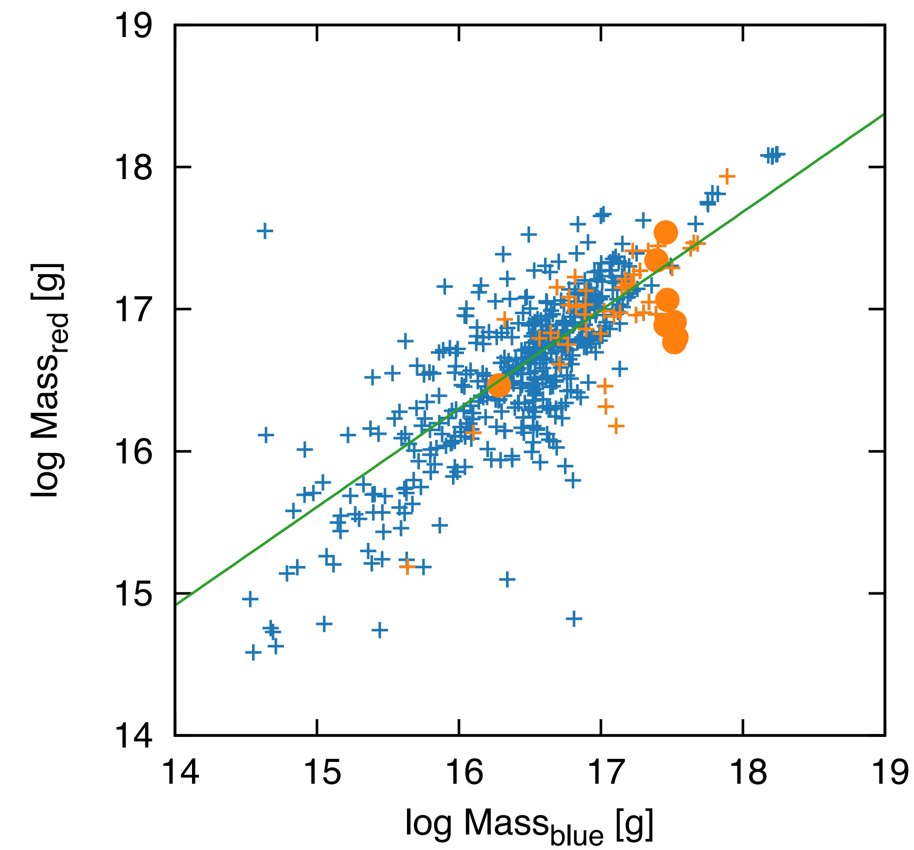
activity indicators are correlated



- Most of the events have their maximum line-of-sight velocities under surface escape velocity (~600km/s)
- Can more events be successful CMEs?
  - If the ejecta is accelerated in the corona to 1–2R_*, larger fraction could escape
  - We see projected velocities only (red/blue ratio disfavors this option)
  - We see only an early phase of the events, before they cool & expand and can be no longer seen in Balmer-lines, but could be still accelerated

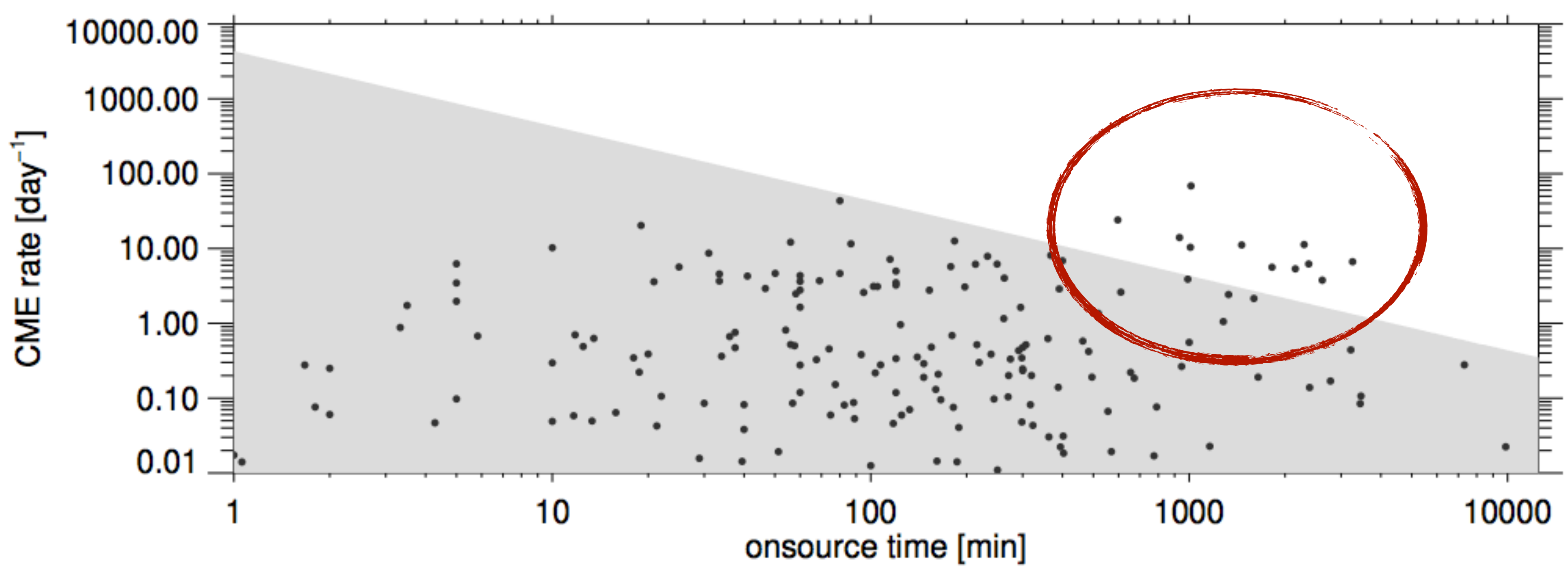






Is there more? Archive data of M-dwarfs

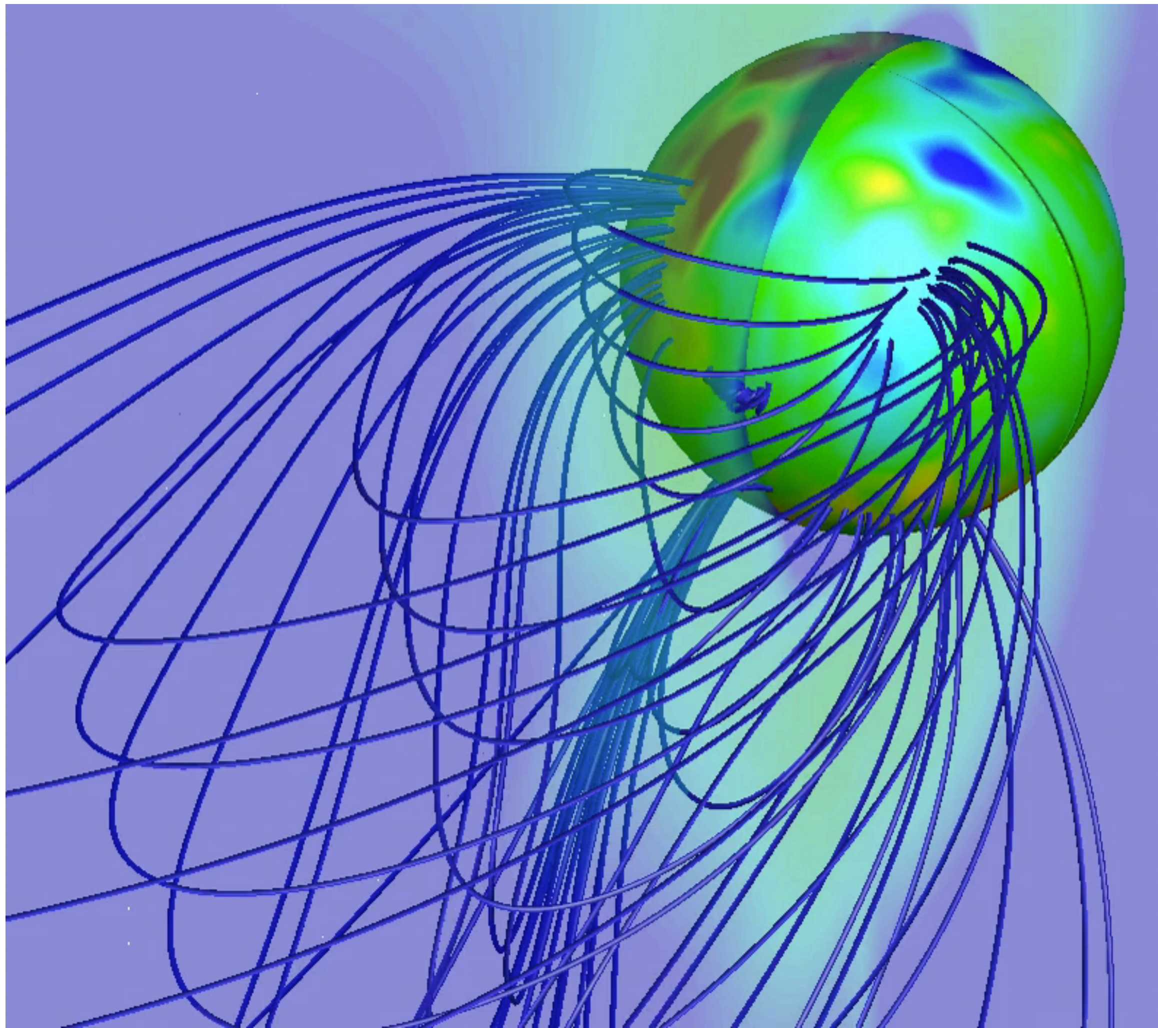
- Archive spectra from ESO/Polarbase of 425 dF-dK targets
- 3700 hours on-source time
- No CMEs! — why?
- Maximum expected CME rates estimated from X-ray luminosity—flare—CME relation are *mostly* within the upper limits for non-detection
- but not in all cases…



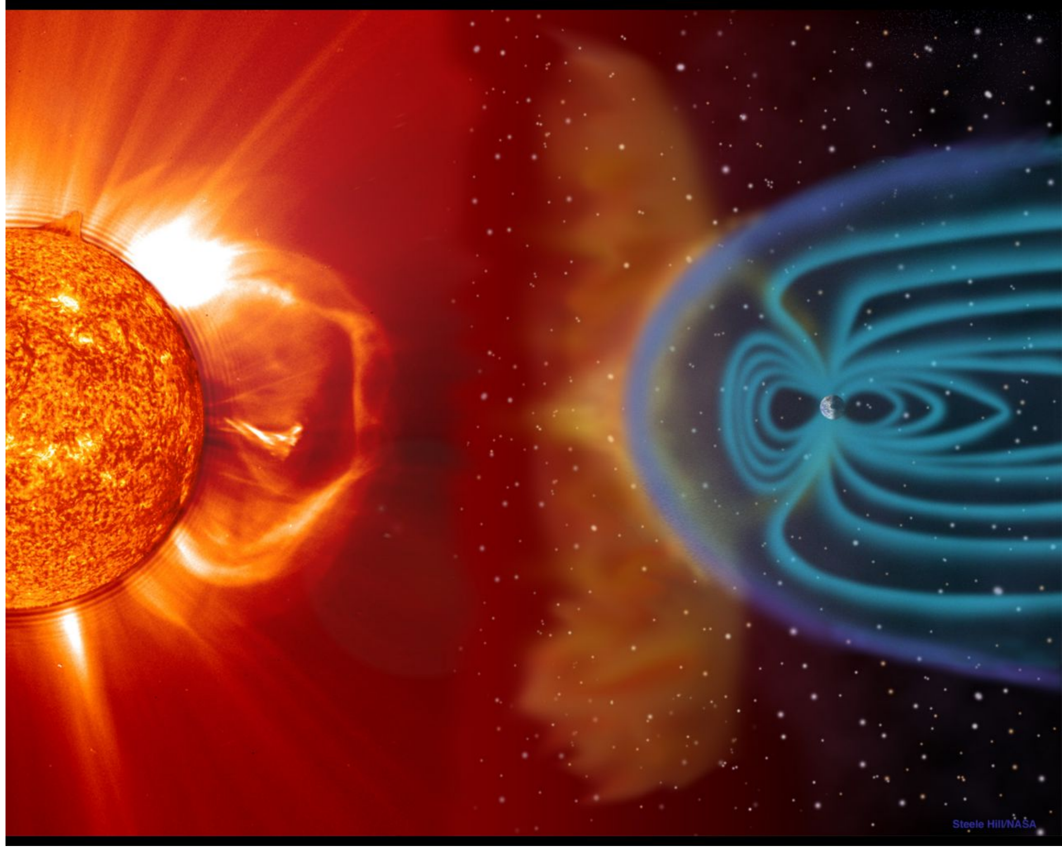
Leitzinger et al. 2020MNRAS.493.4570L

What did we learn?

- On the Sun we see 0.5-6 CMEs/day (depending on the activity cycle)
- On the Sun basically every strong flare is associated with a CME
- From VO data we see rates 1-20 event/day even for late-type stars — lower than we'd expect from a scaled-up solar case (15-60/day); and none on solar-like stars!
- Majority of detected events were associated with enhanced Balmer-lines (flares)
- Maybe we are not detecting many CMEs, because there actually are only few of them? It has been hypothesized that the strong magnetic fields on young stars could actually prevent a filament from erupting in analogy to solar failed eruptions (Drake et al. 2016, Alvarado-Gomez 2018).



What did we learn?



- Successful CMEs are relatively rare on late-type dwarfs: 90-98% of the events are below escape velocity (could be partly chromospheric evaporation)
- Strong magnetic field of the host star could mitigate CME hazards? → even more active stars could provide a safer environment for life as previously thought!
- Flares would still pose a serious threat!

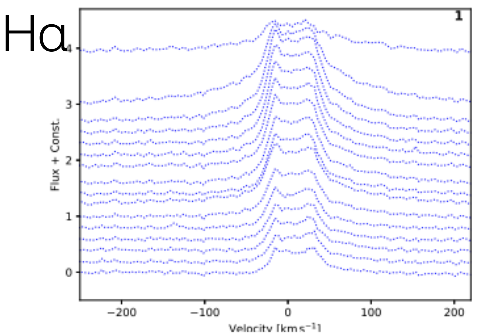
How to continue?

Suboptimal observing strategy in archives (continuous time series are rare) — do we need more targeted observations?

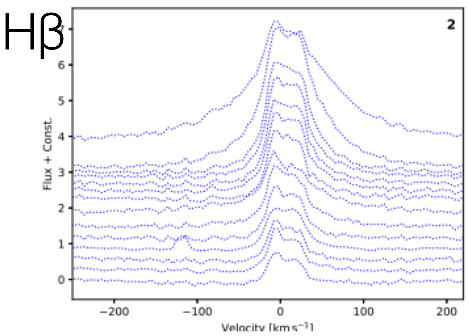
Muheki et al. (2020A&A…637A..13M) — 2000 high-resolution spectra (R ~ 35 000) of the highly active M dwarf AD Leo: 75 line asymmetries with velocities of 80—260km/s, well under escape velocity

(But: i~20° — maybe projection effects?)

Hα



Hβ



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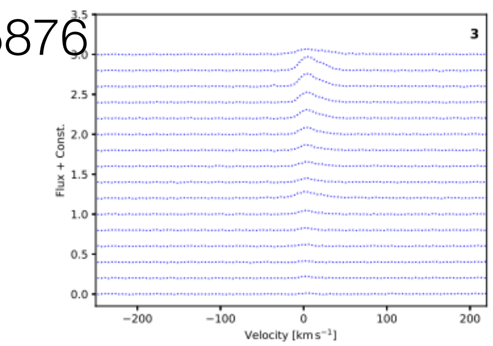


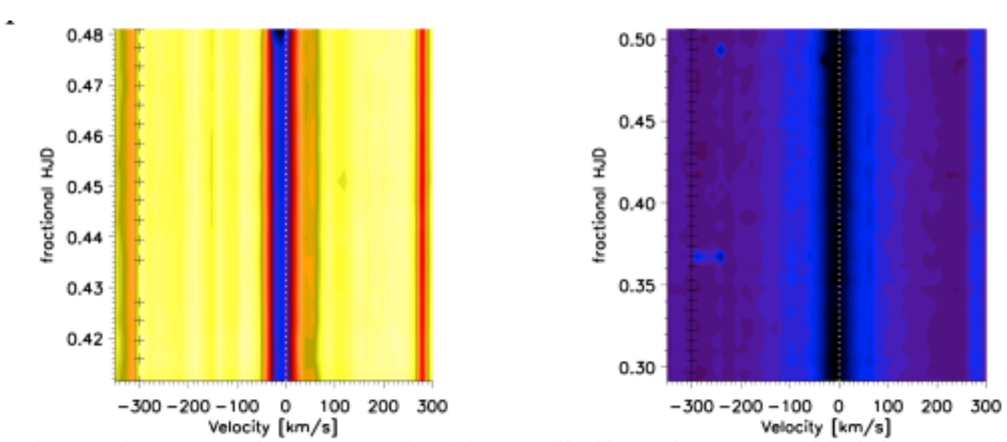
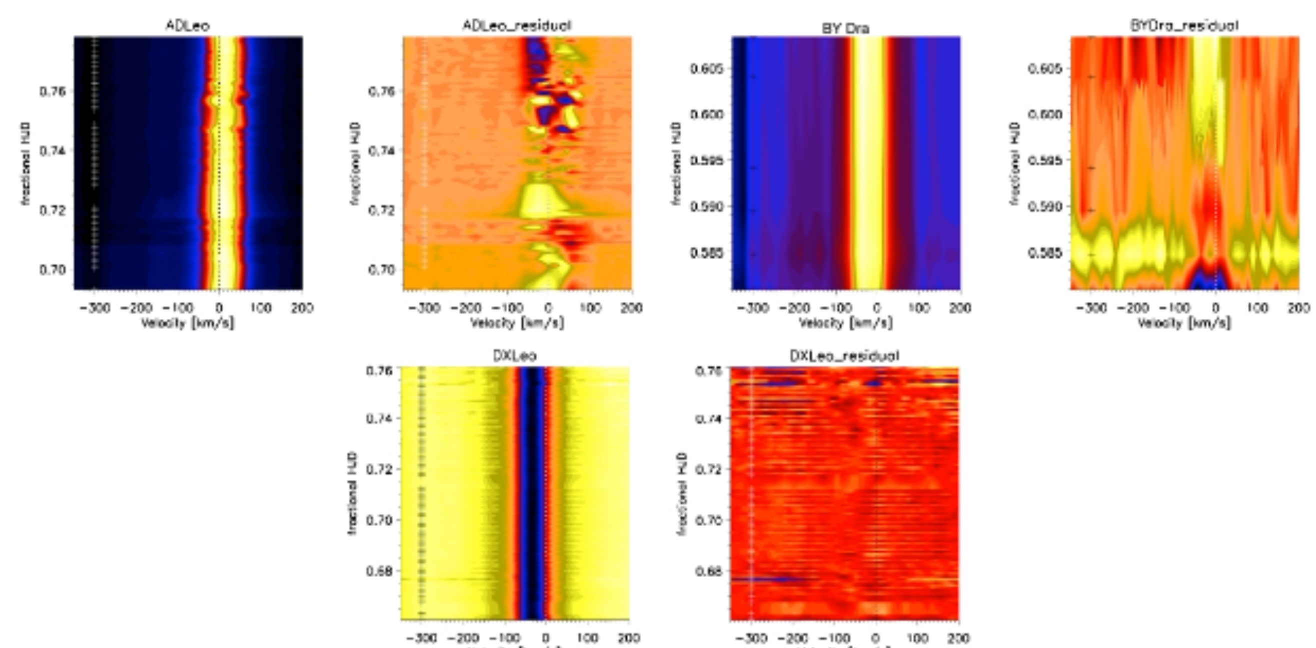


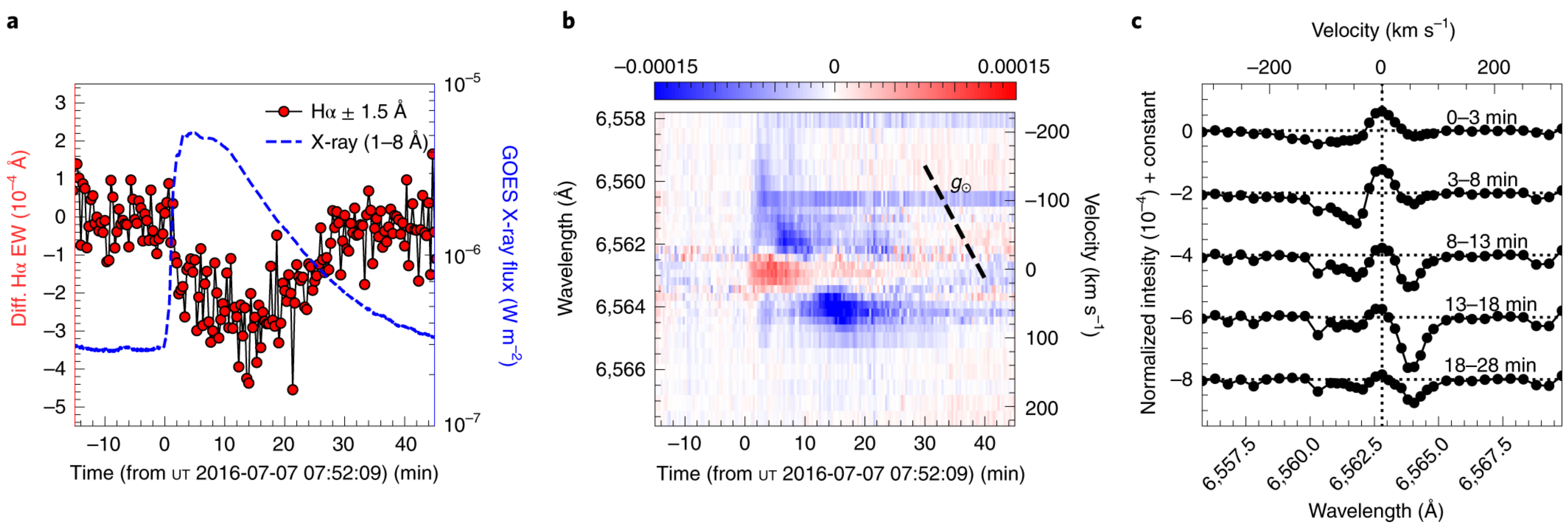
Figure 2. Dynamic spectra for 29 Dra (left) and EK Dra (right).



Avramova-Boncheva+ Cool stars 20.5–21

How to continue?

Successful detection of a CME event on the young solar-type star EK Dra



Namekata+ 2022, *Nat Astron* 6, 241 (probably in the previous talk)

How to move forward?

- Sun-as-a star observations could help? HARPS-N takes spectra of the Sun every 5 minutes for several hours each clear day
- First data release (5 years) in 2020
- Can we build a neural net to reveal known CMEs?

→ new CME indicators?

→ could detect events in archive data / new observations?

- bad news: first look at the data not too convincing, airmass seems to have much more effect than CMEs